September 1985

DCIEM 85-R-37

SCOTT EMERGENCY ESCAPE BREATHING DEVICE - EVALUATION FOR USE IN CF AIRCRAFT

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ABSTRACT

The Scott Emergency Escape Breathing Device (EEBD) was evaluated for use in CF transport/passenger aircraft in providing smoke protection during emergency situations and in preventing hypoxia in the event of a cabin decompression at high altitude. The device was tested initially in the laboratory to assess oxygen production in both ambient and high temperature environments. It was then evaluated, using human subjects for its ability to resist in-leakage of a challenge gas (e.g. smoke), and for its ability to provide a suitable atmosphere to sustain a human at altitude. Test results indicate that there was very little in-leakage provided that the neck seal was maintained; however, one subject with a very small neck experienced considerable in-leakage. The EEBD produced approximately 200 liters of oxygen during its 15 to 17 minutes of operation and maintained a 97% oxygen atmosphere inside the hood on a human subject performing moderate exercise. This atmosphere was maintained while the EEBD was operating, at ground level and at 23,000 feet altitude, and was adequate to maintain arterial oxygen saturation in the subject at 97% at the higher altitude. Temperature in the hood rose to as high as 45.5 deg. C but the subjects continued to function normally. It was concluded that the EEBD would be useful in providing aircraft crewmembers (with the exception of cockpit crewmembers) or passengers with a breathable atmosphere for at least 15 minutes in the event of fire, smoke or decompression at altitudes up to 23,000 feet.

INTRODUCTION

Escape from a fire or smoke-filled aircraft is often difficult or impossible because of incapacitation of passengers or crew from the effects of the smoke, carbon monoxide, cyanide gas, etc. The Air Canada DC-9 disaster at Cincinnati is a prime example. If a source of uncontaminated air were available for as short a time as two minutes in such a situation, lives could often be saved. At present, not all Canadian Forces aircraft crew members and no passengers are provided with such a source of air. Consequently the Medical Life Support Division (MLSD) of the Defence and Civil Institute of Environmental Medicine (DCIEM) was tasked (1) to evaluate the Scott Emergency Escape Breathing Device (EEBD) to determine the degree of protection it would provide passengers and/or crew, which would increase their probability of escape from fire-and/or smoke-filled aircraft. In addition, it was to be tested at altitude to determine if it would provide sufficient hypoxia protection to be used during in-flight emergencies.

The EEBD, shown in Figures 1 and 2, was developed for the United States Navy as a means of escape from a smoke-filled environment below decks on large ships. The EEBD is a Teflon-coated fibreglass cloth hood inside a "Kynol" fabric hood, with a clear polyamide window and a thermoplastic urethane neck seal. The hood acts as a counter-lung to the user's respiratory system. Attached at the nape is a sodium chlorate candle oxygen generator with a lithium hydroxide and molecular sieve scrubber. As shown in Figure 3, the generator powers a venturi "pumping" system arrangement to effect a 55 litres-per-minute circulation through the hood and scrubber. This arrangement ensures delivery of oxygenated air to the user and removes carbon dioxide, excess moisture and any trapped particles. To use, one must pull the actuating pin to start the generator then pull the hood over the head. The EEBD weighs 3.75 pounds, has a ten year storage life in its sealed envelope and an advertised operating life of 15 minutes at 5.5 litres per minute production of oxygen.

Before the evaluation protocol was established, a literature search was conducted to determine the extent of previous testing on the device. The most comprehensive reports available were three test reports (2,3,4) by the manufacturer which, unfortunately, did not provide all the data required. The in-hood atmosphere had been tested for carbon dioxide but not for oxygen content. The in-leakage test depended only on the subject's report of having smelled or tasted the challenge aerosol during only a three-minute exposure. The high-temperature test was limited to operating the EEBD in ambient temperatures after a hot-soak. The carbon monoxide measurement test did not use human subjects, nor the complete EEBD. Because of these deficiencies, it was deemed necessary to proceed with further evaluation.

From the testing carried out, it was found that the hood operates as designed and advertised, and can protect the wearer from hypoxia at altitude for as long as the generator operates.

Figure 1. EEBD Test Set-Up Showing Sampling Lines

Figure 2. EEBD Showing Septal Neck Seal

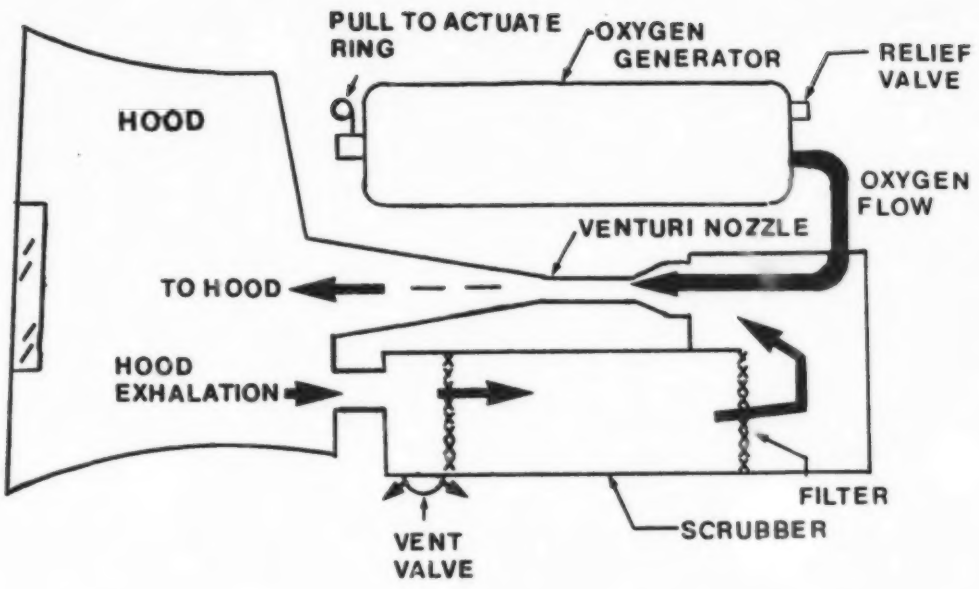

Figure 3. EEBD Schematic

TEST METHODS

General

Testing was carried out in four phases, as follows: gas production analysis, high temperature operation, in-leakage measurement and high altitude operation. These phases are detailed below. Each test was performed five times using a new hood each time, to assess the reliability of the method.

Gas Production Analysis

Five hoods were tested in a laboratory to determine volume produced, oxygen purity, and generator operating time. The laboratory testing consisted of mounting a complete EEBD hood on a mannequin head, activating the unit and drawing off the gas produced through a Tygon tube to a 200 litre mylar bag. The gas was analysed using a Bio-Marine OM-300 analyser calibrated with a "zero-gas", with 95% oxygen and with ambient (21% oxygen) air. The gas from the bag was sampled and passed over a Rexnord oxygen sensor; results were recorded on a Pedersen strip recorder. For confirmation, samples were also tested on a Taylor oxygen analyser.

High Temperature Operation

It was necessary to determine how well the generator would work in high temperatures such as would be experienced in a fire/smoke emergency. To simulate such an exposure, a mannequin head, modified with an internal rubber hose leading from the mouth to the front of the neck, was put in the DCIEM Tenney Environmental Oven which had been pre-heated to 80 deg. C. A temperature probe and a Tygon sampling line were sealed in the rubber hose, and routed through the oven wall to a cooler coil, then to a thermometer and finally, a Rexnord oxygen sensor. The cooler was used as insurance, to preclude erroneous readings in case the oxygen sensor was affected by high temperature. Temperatures inside the hood, and of the gas sample being extracted, were noted and recorded manually. The sensor output was recorded on a Pederson recorder. A DuPont P4000 pump was on hand but used only when the oxygen flow from the hood started to diminish. A new EEBD hood was then placed on the mannequin head, the generator was activated and the readings were recorded. The procedure was repeated with four more hoods. No attempt was made to evaluate the hood on a human subject in a very hot environment because of the hazard to the subject.

In-Leakage Measurement

In order to evaluate the protection afforded by the EEBD against toxic gases, it was necessary to measure the leakage into the hood under simulated emergency conditions. Five healthy human volunteers, three male and two female, were used for this third phase of testing conducted in the DCIEM satellite hypobaric chamber. The subjects were selected to provide a wide distribution in size, particularly neck circumference.

The subject's relevant anthropometric data are shown in Table 1.

Table 1. Subjects' Anthropometric Data

Subject	M/F	Head Circumference cms.	Percentile **	Neck Circumference * cms.	Percentile **
A	M	57	30	38	25
B	F	56	75	33	50
C	F	54.5	37	29	1-5
D	M	57	30	41	75
E	M	57	30	36	5
F	M	56	12	38	25

** CF Personnel (5,6)

* Note: The measuring tape is held in a plane perpendicular to the long axis of the neck. The circumference of the neck is measured just below the bulge of the thyroid cartilage ("Adam's Apple").

All runs were recorded on video-tape. The subject entered the chamber and sat on a bicycle ergometer. As a safety precaution because of the high temperatures experienced inside the hood while the subject was exercising, he/she was connected to a Tektronix 408 ECG monitor, and heart rate was continually monitored by ECG wave form using a standard three-lead system. The subject donned a standard aircrew oxygen mask and breathed 100% oxygen while the chamber was flooded with carbon monoxide (CO) until a concentration of 5000 parts per million (ppm) was reached. Carbon monoxide was chosen as the challenge gas because of its ease of detection in very low concentrations. The concentration was chosen in consultation with the Human Sciences Section specialist as being non-toxic over the exposure period. The subject then started the oxygen generator of the EEBD, held his/her breath, discarded the oxygen mask and donned the hood. He then commenced pedalling the ergometer at 80 watts output. Gas from inside the hood was sampled through ports in the EEBD face window close to the mouth as shown in Figure 1. These gases were routed outside the chamber to carbon monoxide and oxygen sensors which had been calibrated with 500 ppm CO and 100% oxygen respectively. The carbon monoxide and oxygen levels were recorded on strip charts. Temperatures inside the hood and in the chamber were recorded manually. The test continued until the subject heard the EEBD generator begin to slow. The subject then removed the hood and quickly exited the chamber. Alveolar air samples were taken before and after the run to determine carboxyhaemoglobin (COHb) rise.

High Altitude Operation

The capability of the EEBD hood to provide hypoxia protection at altitude was tested using subject exposed to a simulated pressure altitude of 23,000 feet. Six subjects were selected for this phase. For reasons of safety, the subjects' medical records were screened by a Flight Surgeon for any history of conditions which could pose a hazard during the testing. The subjects all held a current High Altitude Indoctrination (HAI) certificate, necessary for the high altitude testing of Phase IV. The subject had a Doppler blood flow base-line check just prior to the test. The subject and an inside observer had both been cleared by a Flight Surgeon for the exposure to reduced pressure. The subject's arterial oxygen saturation was measured continually with a Hewlett-Packard H-P 47201A ear Oximeter and the heart rate was monitored as in the previous runs. To wash nitrogen from the blood, the subject and observer breathed only 100% oxygen for 30 minutes prior to the test. When all preparations were complete, the subject was seated on the bicycle ergometer and the oximeter probe was mounted on the ear and recalibrated. After a standard ear/sinus check was completed, the chamber altitude was raised to 8,000 feet. At this time the subject activated the EEBD generator, held his breath, removed the oxygen mask, donned the EEBD hood and resumed breathing. The oximeter provides an "OFF EAR" light if the probe is not properly positioned on the ear, and this was monitored continually. When an "OFF EAR" indication occurred, the subject and observer attempted to reposition the probe. If this attempt was unsuccessful after five minutes, the run was aborted because the remaining generator running time would not have been adequate for the test period. If no "OFF EAR" indication was observed, the chamber was decompressed rapidly (in approximately 15 seconds) to 32,000 feet. The subject's arterial oxygen saturation was closely monitored and was not to be allowed to go below 70%, the level considered safe for the experiment. The altitude was allowed to stabilize for approximately 30 seconds, then a descent at 5,000 ft/min. was established and the chamber brought down to 22,000 feet. At this time the subject began to exercise on the ergometer, continuing until the EEBD generator began to slow. When the EEBD was exhausted, the subject held his breath, removed the hood and donned a standard oxygen mask. The chamber was then brought to ground-level pressure and the subject exited. Immediately after the run the subject was checked for nitrogen bubbles in the bloodstream using the Doppler blood flow monitor.

RESULTS

Gas Analysis

The results of the gas analysis showed that approximately 120 litres of gas was produced from each generator run. Of the five generators tested, test results of two had to be discarded because of problems in sampling. Analysis of the gas inside the hood from the remaining three runs showed approximately 65% oxygen content after one minute of operation, 87% after two minutes, 95% after three minutes and a steady-state level of 95% to 100% at about six minutes. The peak oxygen levels

recorded from different runs were from 95% (e.g. Figure 4) to 100%. These results were confirmed by the Taylor analyser using bagged samples taken at five-minute intervals. Rate of increase in oxygen level was the same in each sample. The running life of the generators was from 15 1/2 to 17 1/2 minutes, at which time the oxygen percentage in the sample dropped sharply.

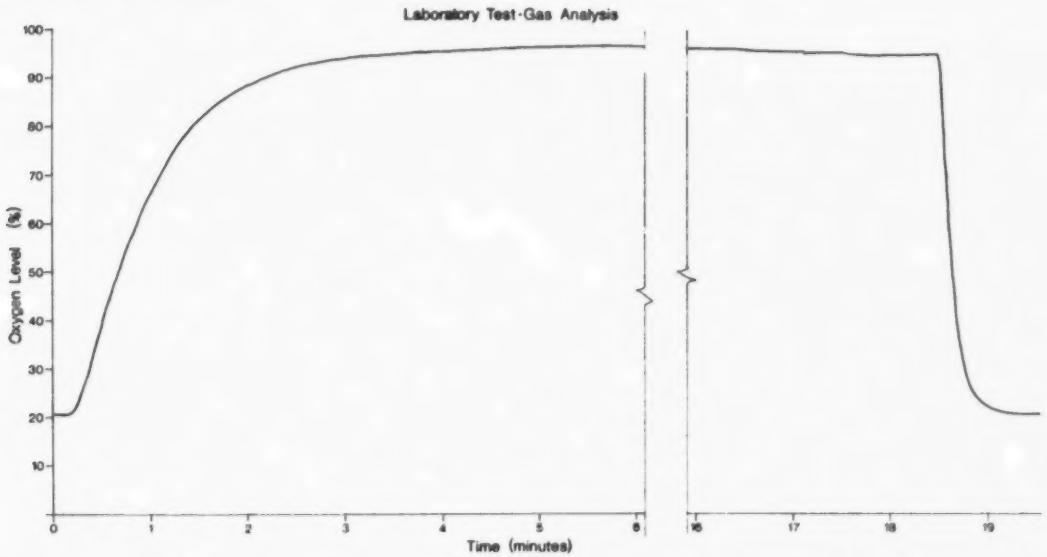

Figure 4. Example EEBD Generator Gas Analysis (Run 3)

High Temperature Operation

In the hot environment the EEBD's operated normally, producing the same oxygen content rise rate and achieving the same concentration levels. The operating life of these generators was from 14 1/2 to 17 minutes. The gas sampled during the running period was 90-100% oxygen, with the peak above 97% in all runs, as indicated in Figure 5. The temperature inside the hood and the temperature of the gas being sampled were recorded at 30-second intervals (Table 2).

Table 2. In-Hood and Sample Gas Temperatures

Run No.	Sample Gas Temperature (^{O}C) Minimum	Maximum	Hood Temperature (^{O}C) Minimum	Maximum	(At Time Elapsed) [min]
1	22.9	24.3	60.1	74.8	(14:00)
2	23.7	24.4	53.6	70.0	(15:00)
3	24.5	24.6	52.5	62.9	(16:30)
4	22.6	23.5	32.5	60.7	(15:00)
5	22.8	23.2	57.5	66.6	(17:30)

The inside temperatures during the first run (74.8 deg. C maximum) were higher than in subsequent runs because the first EEBD was subjected to an unplanned hot-soak for 55 minutes before the generator was activated. On subsequent runs, hot-soaking was limited to the few minutes of set-up time before the run started.

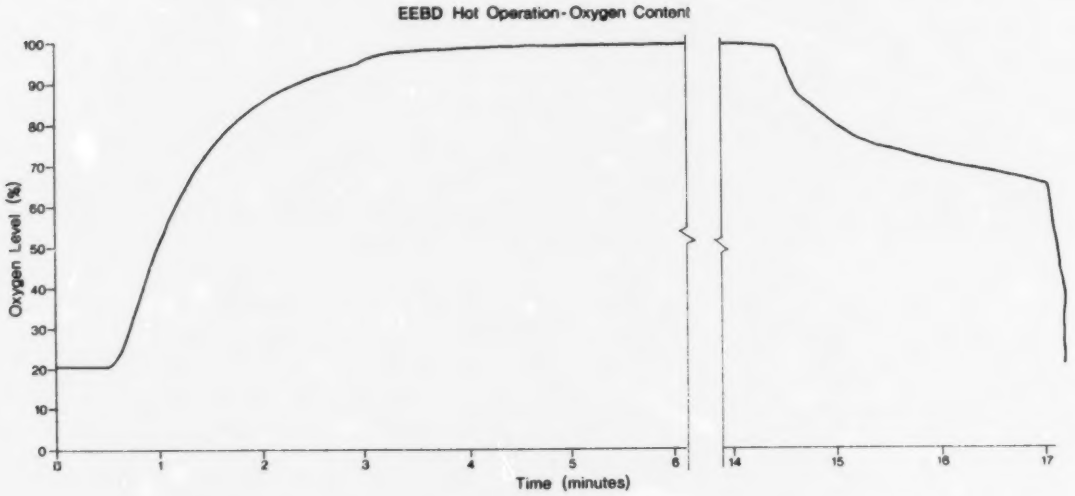

Figure 5. Example EEBD Generator Gas Analysis Run 1

In-Leakage Measurement

The results of the ground-level in-leakage test runs are indicated in examples of the under-hood gas analyses presented in Figures 6 to 13.

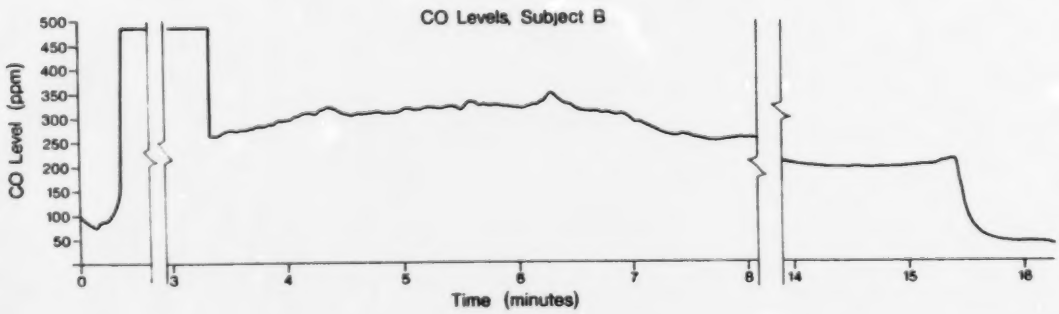

Figure 6. Carbon Monoxide Level - Run 2

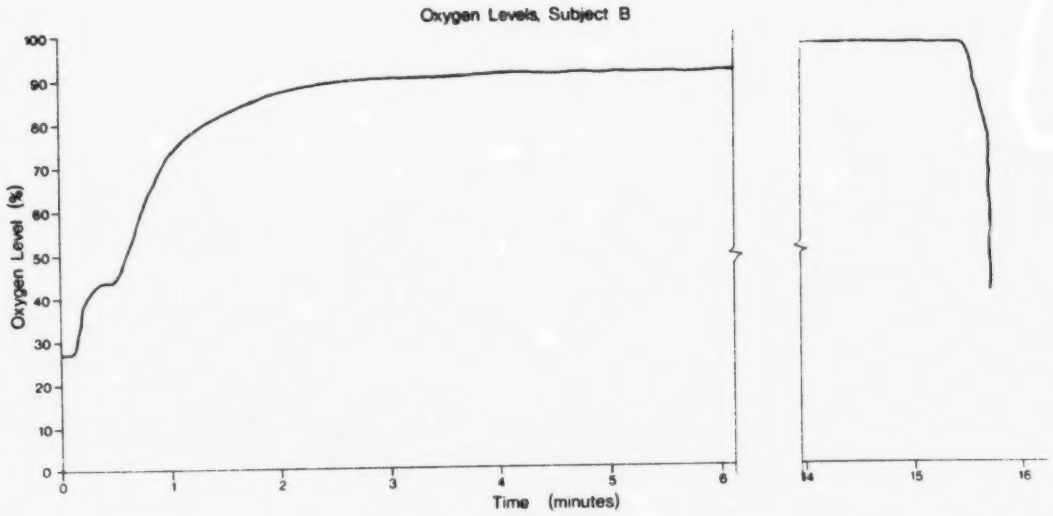

Figure 7. Oxygen Level - Run 2

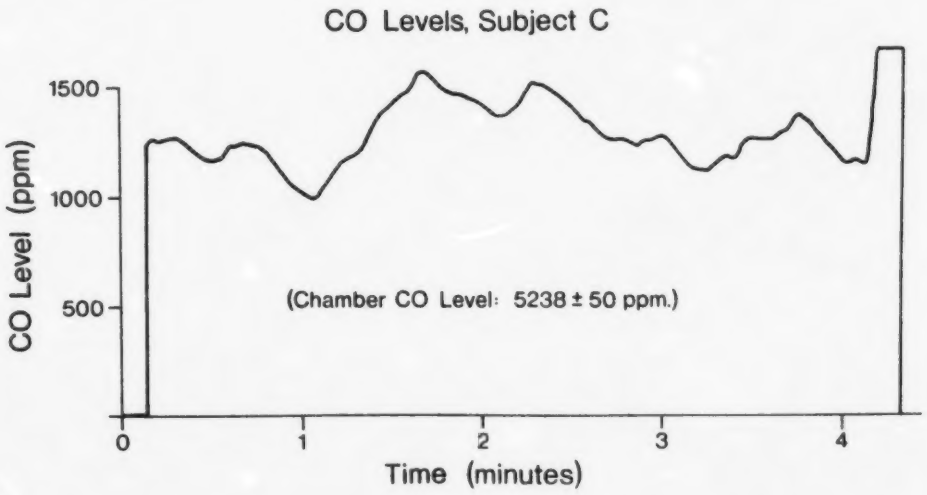

Figure 8. Carbon Monoxide Concentration - Run 3

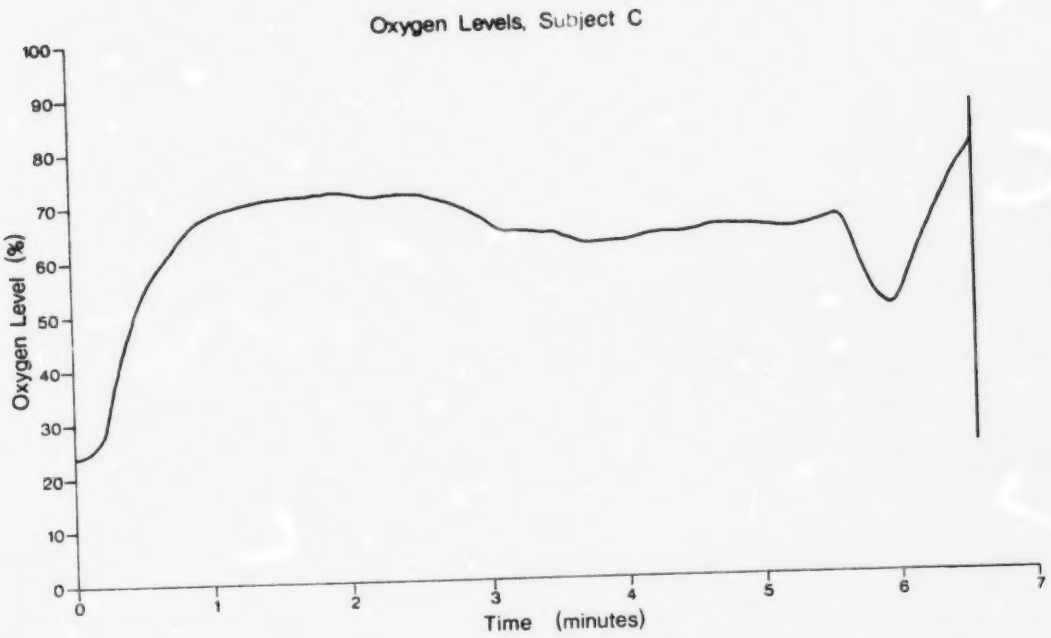

Figure 9. Oxygen Concentration - Run 3

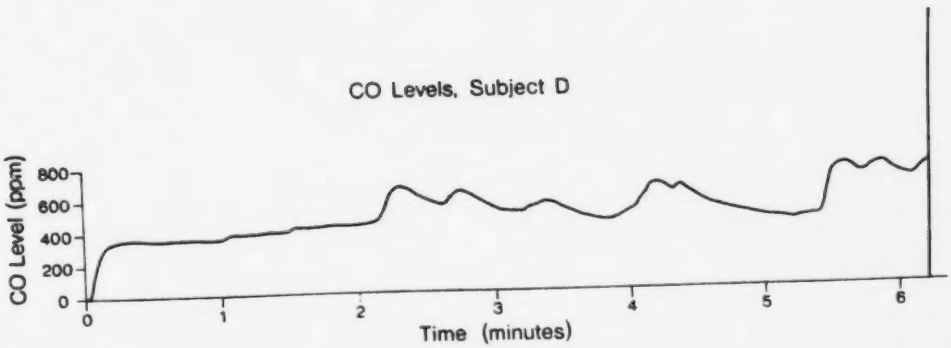

Figure 10. Carbon Monoxide Concentration - Run 4

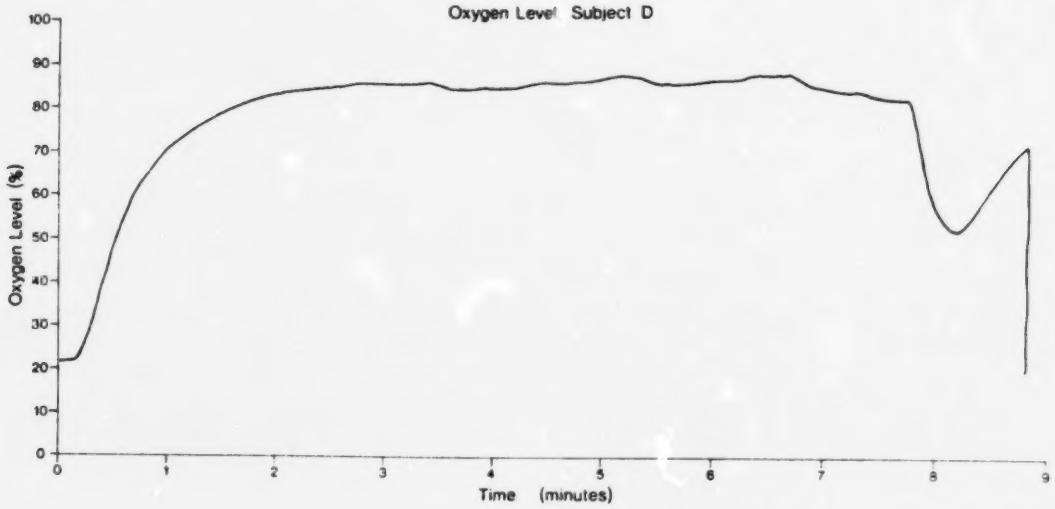

Figure 11. Oxygen Concentration - Run 4

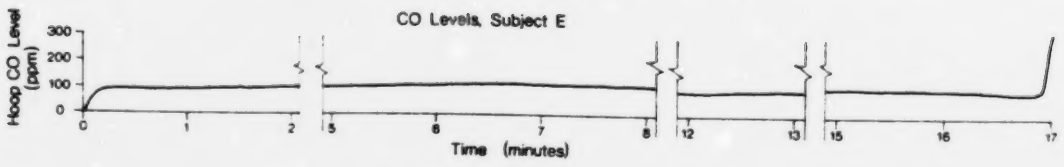

Figure 12. Carbon Monoxide Concentration - Run 5

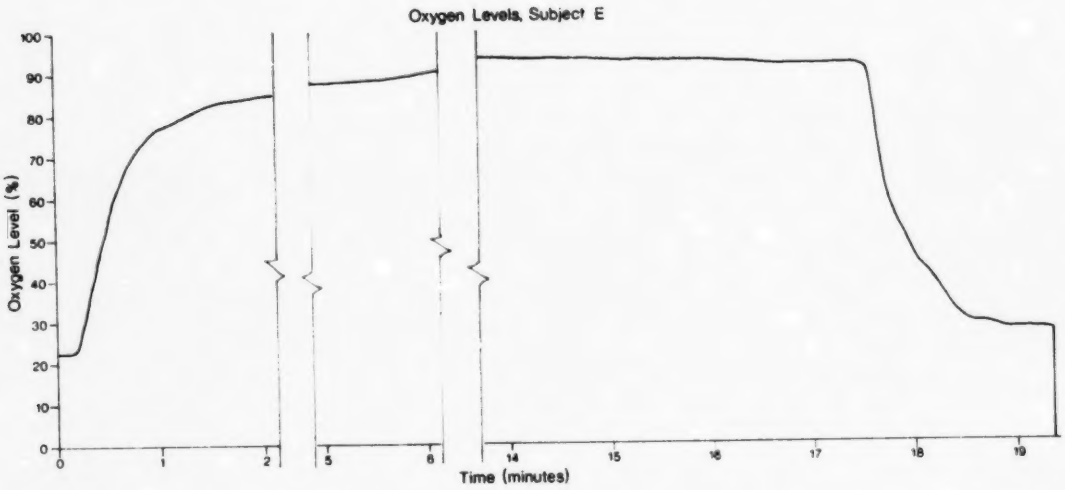

Figure 13. Oxygen Concentration - Run 5

No run was completed for subject A; it was aborted due to a procedural misunderstanding. In all five runs the oxygen level started at 18-20% and rose rapidly, reaching at least 70% in one minute. In three of the five runs a level of 75% was reached in the first minute. The oxygen level on run three failed to reach 75%, and the run was terminated at four and one half minutes. The CO levels for run 3, shown in Figure 8, were high; they rose immediately at the start and peaked at 1600 ppm. This run was terminated because of the abnormally high CO level. Similarly, the CO levels in run 4, shown in Figure 10, were higher than expected, at up to 700 ppm. Although the oxygen level was 85% or better, this run was terminated at seven minutes 30 seconds because of the CO levels. Post-run alveolar air samples confirmed these termination decisions, revealing an 8.8% carboxyhaemoglobin (COHb) in Subject C (run 3), a non-smoker, and 16% COHb in Subject D (run 4), who was a smoker. (Subject D subsequently breathed 100% oxygen until the COHb dropped to his normal level.) Because of the high readings, the CO level in the chamber was reduced to 1000 ppm for run 5. Post-run alveolar air samples from the last subject (run 5) showed no rise in COHb after the run. The relative temperatures taken during the run, shown in Table 3, indicate again the conditions inside the hood.

Table 3. Ambient and Under-Hood Temperatures - Ground Level Runs

Subject	Ambient Temperature (°C) Minimum	Maximum	Hood Temperature (°C) Minimum	Maximum	(At Time Elapsed) [min]
A	21.4	21.4	22.7	34.8	(4:00)
B	19.2	22.7	20.8	41.5	(15:00)
C	18.7	19.9	20.6	28.4	(4:30) *
D	19.6	23.1	23.6	36.3	(7:30) *
E	20.0	21.8	23.2	45.5	(17:30)

* run aborted before completion

High Altitude Operation

Three test runs had to be terminated before the rapid decompression because the oximeter probe came off the ear during hood donning and could not be properly repositioned. After fabricating a new oximeter mount suspension and changing donning procedures slightly, four successful runs were completed. None of the subjects had any problems during the run. Their arterial oxygen saturation never fell below 97% and no decompression sickness was experienced during or after the tests, despite exercising at altitude. Subject C, with the smallest neck, could not complete the altitude run because of oximeter problems; subject B, however, with the next-to-smallest neck, did. The oxygen levels for subject B were not lower than those of other subjects, as might have been expected. The temperatures inside the hood, shown in Table 4, increased with time, the maximum recorded being 45.5 deg. C during ground-level run 5. The maximum temperature during an altitude run was 41.1 deg. C on run 3, with subject D. Despite the relatively high temperatures inside the hood, no subject complained of unacceptable heat levels during the test run, even while exercising.

Table 4. Ambient and Under-Hood Temperatures — Altitude Runs

Subject	Ambient Temperature (°C) Minimum	Maximum	Hood Temperature (°C) Minimum	Maximum	(At Time Elapsed) [min]
A	21.0	25.3	23.1	30.4	(10:00) *
B	21.7	24.4	21.0	30.5	(10:00) *
C	20.1	24.3	21.9	38.5	(16:45)
D	19.2	25.5	21.4	40.0	(16:30)
E	18.9	26.2	23.1	41.4	(17:00)
F	19.2	24.0	21.9	38.7	(16:30)

* run aborted before completion

General

Although the subjects could generally see well through the clear hood window, details such as numbers on the ergometer speedometer were blurred and unreadable. This problem was caused in large part by the crease in the center of the window where the hood had been folded in its container. There was no noticeable misting of the face-piece during the trials even though one subject experienced heavy facial perspiration because of the heat, which resulted in sweat getting in her eyes. Communication was difficult because of the noise inside the hood from the generator. (The generator discharges into the hood near the subject's right ear.) For most subjects, the hood collapsed around their heads and the neck seal was sucked up against their chins with each breath.

DISCUSSION

High Temperature Operation

The slightly shorter operating life of the generators in an elevated temperature recorded in these trials agrees with results reported by the manufacturer (4), using EEBDs which had been hot-soaked at 140 deg. F (60 deg. C). The Scott reports explain that the generator reaction is accelerated as the temperature rises (and slowed down as temperature drops) with an attendant increase in oxygen production.

In-Leakage

Only two of the five subjects experienced significant in-leakage. There is a limited volume of gas available as a "counter-lung" when the hood is on the head. This causes the collapsing of the hood with each breath which is the main reason for the in-leakage experienced. This is especially valid for subject C whose very small (29 cm. circumference) neck did not fill the minimum circumference (33 cm.) of the seal. This leakage was anticipated. Nonetheless, the hood maintained 60% or better oxygen concentration even with the gross leakage. The high leakage rate experienced by Subject D in run 4 was unexpected and probably due to the hood being improperly positioned on the head. This could have pulled up the septal neck seal and prevented it from forming a good seal with the neck. It was assumed that in a real emergency the subject would be unaware of a loose neck seal, hence no attempt was made during the tests to improve the seal.

Altitude Protection

The low pressure inside the EEBD hood in operation, relative to the sampler which was outside the chamber, precluded sampling the gas being breathed by the subject. As a result the blood-oxygen level, continually monitored throughout the run, was the only check on the percentage of oxygen being received by the subject. The problems in donning the hood without disturbing the ear oximeter were greater than anticipated but a redesigned suspension and a moleskin skullcap helped

considerably. Although subject C with the smallest neck could not complete the altitude run, the positive results of subject B's run indicate that neck size is not a great problem during a high-altitude exposure. The fact that high blood-oxygen concentration levels were maintained by the EEBD shows that it is effective in preventing hypoxia.

CONCLUSIONS

From the results obtained during this evaluation, the following conclusions were drawn:

a. The consistency of the results indicates that the testing methods were reliable;

b. The Scott EEBD operated as advertised. It generated oxygen of 95-100% concentration for 14 1/2 to 17 1/2 minutes. Concentrations inside the hood worn by a human subject rose from ambient (20%) to 75% in approximately 70 seconds, then to near the 100% level until the generator failed;

c. The Scott EEBD performance at 80 deg. C was comparable with its performance at ambient temperatures, except that generator operating life was shortened slightly with increased temperature;

d. In-leakage in a hostile breathing environment was minimal with subjects whose neck circumference was greater than 33 centimeters. For subjects with smaller necks, in-leakage was much greater, but in a life-threatening situation this factor should not prejudice use of the EEBD;

e. The EEBD was able to prevent hypoxia of crew members for 15 to 17 minutes following a simulated typical accidental decompression of a pressurized aircraft. It must be noted, however, that their crew functions could be impaired due to the loss of visual acuity, hearing impairment, and slight impairment to free movement in confined spaces; and

f. Although the use of the EEBD created some discomfort and minor distress in the users, the device performed well, proving its ability to save lives in the given circumstances.

RECOMMENDATIONS

The Scott EEBD should be considered for introduction in CF aircraft as necessary, primarily to increase passengers' and/or crew members' chance of escape from a fire- and/or smoke-filled aircraft, and secondarily, to provide hypoxia protection. However, because the hood window adversely affects vision, the EEBD should not be considered for crewmembers such as the cockpit crew who would require a high degree of visual acuity.

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